Cotton Response to Subsurface Drip Irrigation Frequency Under Deficit Irrigation

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Abstract. *Cotton lint yield and quality were investigated for different irrigation frequencies using subsurface drip irrigation (SDI) under limited water conditions (1.7 mm day^{-1}) in the St. Lawrence region of West Texas. Two frequency intervals were studied during two years; these intervals were 4 and 16 days in 1999 and 2 and 8 days in 2000. Each treatment was replicated four times, and the total amount of water applied each year was the same. The soil was a silty clay loam soil underlain by caliche just below 90 cm from the surface. In both years, there were no significant differences between frequency treatments in lint yield, micronaire, fiber length, fiber strength, uniformity, or gross returns. Using the loan values as an indicator of lint quality, cotton loan values were highly significant in 1999, but were not different in 2000. With no major advantage in increasing irrigation frequency using SDI under deficit conditions, these results may have an impact on the agronomic practices of the region where water is very limited. Low frequency irrigation may allow farmers to have more flexibility in managing their irrigation systems and avoid the additional expense of automating a microirrigation system.*

Keywords. *Water management, Irrigation scheduling, Microirrigation, Deficit irrigation.*

The economic sustainability of cotton production of the arid and semi–arid areas depends on attaining high water use efficiencies (cotton lint yield per unit of water applied) through good irrigation management, which generally implies a strategy to minimize water evaporation, runoff, and deep percolation. This improved management is crucial in areas such as the St. Lawrence region of West Texas, where irrigated agriculture is almost totally dependent on groundwater, and where the very limited capacity wells usually preclude fully irrigating a crop. The management strategies are highly dependent on the irrigation method used, which generally is furrow irrigation (FI), low energy precision application (LEPA), or subsurface drip irrigation (SDI).

For furrow systems, some management strategies to reduce runoff are to irrigate portions of the furrow length (Stewart et al., 1981) or to use tailwater recovery systems. Some strategies for reducing deep percolation are to irrigate with alternate furrows (Musick and Dusek, 1974), to compact furrows (Khalid and Smith, 1978), and surge irrigation (Trout and Kemper, 1983). Management strategies for LEPA systems are to dike the furrows to reduce runoff and to irrigate frequently to reduce deep percolation (Bordovsky et al., 1992). For SDI systems, most of the cotton irrigation strategies have been directed toward reducing evaporation either by reducing the row spacing and pattern (Enciso et al., 1999; Unruh et al., 2000) or by using different tillage practices (Bordovsky et al., 1994); frequent irrigation has been used as strategy to reduce deep percolation (Bordovsky and Lyle, 1998).

A general premise for high frequency irrigation (e.g., intervals of 1 to 7 days) is that light, frequent irrigations increase water use efficiency, either by reducing deep percolation or reducing crop water stress, resulting in greater yields. Pressurized irrigation systems (e.g., LEPA and SDI) generally lend themselves to high frequency irrigation because they can spread the water more quickly and uniformly over the entire field (Martin et al., 1990). However, high frequency irrigation has been also used successfully with surface irrigation methods in the cases where drip or pressurized systems are not economically feasible (Hunsaker et al., 1998). Radin et al. (1992) studied the response of cotton using high frequency furrow irrigation during specific growth periods. They found that increasing the number of irrigation events for a short period during peak fruiting increased yield when the same amount of water was applied. They attributed the higher water use efficiency to physiological reasons and explained that drip irrigation and mid–cycle supplements increased midday leaf water potential and apparent hydraulic conductance of the plants for an extensive period during fruiting. This higher frequency irrigation in turn enhanced the water uptake and transport capacity of the cotton plant.

Henggeler (1988) observed that cotton yields using drip irrigation were generally greater with shorter intervals for the same amount of water, although he noted some studies

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observing no yield increases once intervals were shorter than about 7 to 10 days. In a comprehensive review of SDI, Camp (1998) observed that irrigation intervals shorter than seven days did not affect corn yield provided soil water was adequate; however, results were mixed for shallow rooted vegetable and fruit crops. Hutmacher et al. (1995) reported similar yields and afternoon leaf water potentials of three cotton varieties subjected to various levels of deficit SDI at various growth stages. They attributed these similarities to a clay loam soil that afforded both deep root development and a large soil water holding capacity. In a more extreme example, DeTar et al. (1994) compared cotton yields for SDI and furrow irrigation on both a highly variable sandy soil and a uniform silt soil over four years. Yields were significantly higher for SDI on the sandy soil but were nearly the same on the silty soil, although water use for SDI was about 40% less in all cases. They concluded that soil quality rather than type of irrigation system (which implies frequency) most influenced yield differences. Bordovsky and Lyle (1998) studied the effect of irrigation frequency and delivery rate on cotton yield using both SDI and LEPA, where SDI frequency was daily and LEPA frequencies were 1, 2, and 3 days, and maximum delivery rates were 2.5, 5.1, and 7.6 mm per day. They reported that both lint yield and water use efficiency were significantly greater for SDI than all LEPA frequencies, but there were no significant differences between LEPA frequencies except for the lowest delivery rate (2.5 mm day^{-1}). They attributed the greater lint yield and water use efficiency of SDI to reduced soil surface evaporative loss compared to LEPA (which would increase water availability in the root zone) rather than irrigation frequency.

Several agricultural users in water limited areas of west Texas have delivery rates of 1.5 mm day^{-1}, and the precipitation rates vary from 350 to 400 mm annually (Henggeler, 1998). Very few studies have been conducted on the effect of high frequency irrigation on water use efficiency and its effect on cotton quality under extreme water limiting conditions using SDI. Some farmers in far west Texas justify long intervals with SDI systems by the high water retention characteristics (medium to fine textured soils) and deep soils; furthermore, they argue that when water is very limited, the water that is lost to deep percolation is negligible. The objective of this study was to evaluate the effect of different irrigation frequencies on cotton lint yield and quality under water limiting (deficit irrigation) conditions.

MATERIALS AND METHODS

The experiment was conducted on a commercial farm in St. Lawrence, Texas. The area was semi–arid and received less than 400 mm of rainfall per year (table 1). A genetically modified cotton variety with Bt traits (*Gossypium hirsutum L*., c.v. Deltapine’s NuCoTN 33 B) was planted in 1999 and c.v. Deltapine 458BR was planted in 2000, to limit insect damage and its influence on the experiment. The soil at the field site was a Reagan silty clay loam (fine–silty, mixed, thermic Ustolic Calciorthids) soil with moderate permeability on a 1% slope. The soils were underlined by calcareous loamy sediment. The water holding capacity in the first 0.75 m was 177 mm m^{-1} of soil. From a depth of 0.75 to 2.0 m the water holding capacity was 132 mm m^{-1}. These soils had a water intake rate of about 30 mm h^{-1}.

Table 1. Agronomic data for the 1999 and 2000 cotton seasons.

Operation	1999	2000
Pre–season irrigation dates (depth applied)	15 Feb. to 15 May (114 mm)	20 Jan. to 11 May (175 mm)
Planting date	May 17	May 11
In–season irrigation dates (depth applied)	11 June to 8 Sep. (134 mm)	13 May to 11 Sep. (165 mm)
Growing season rain[a]	148 mm	130 mm
Total irrigation plus rain	396 mm	470 mm
First N–injection	3 July	7 July
Second N–injection	15 July	21 July
Third N–injection	29 July	4 August
Seasonal degree–day (15.6°C)[a]	1316	1593
Harvest date	4 November	30 October

[a] Cumulative values from planting until harvest each year.

The experiment consisted of applying the same amount of water within each year but with different irrigation intervals, which were 4– and 16–day during 1999, and 2– and 8–day during 2000. The two treatments were replicated four times both years. Each of the eight plots had an area of 0.578 ha consisting of 25 rows spaced at 1.02 m and with a row length of 219 m. The irrigation intervals were adjusted in 2000 based on the 1999 results as well as those of Bordovsky and Lyle (1998) **,** which suggest irrigation intervals of less than three days produced higher lint yields. The ratio for the irrigation intervals was the same in both years in that the low frequency irrigation was four times greater than the high frequency treatment.

Cotton was irrigated using a subsurface drip irrigation (SDI) system with solenoid controlled electric valves that were activated with an automatic timer. A dripline was installed between every other row (alternate furrows) at a depth of about 0.3 m below the soil surface, and the emitters were directed upward. The dripline had 0.57 L h^{-1} emitters spaced every 0.3 m. A single well with a small capacity of 0.88 L s^{-1} provided water to all plots for a delivery rate of 1.7 mm day^{-1}.

Table 1 shows agronomic data for the 1999 and 2000 seasons. A preseason irrigation was applied to refill the soil profile to field capacity in time for planting during both years, as the low capacity of wells typically found in the region limit irrigation capacity below that of mid–season peak consumptive use. In 1999, an irrigation depth of 114 mm was applied prior to planting (15 February to 15 May) and 134 mm in–season (11 June to 8 September). The rainfall received during the first season was 148 mm of water. Total irrigation plus rain for 1999 was 396 mm. Plots were harvested on 4 November. In 2000, an irrigation depth of 175 mm was applied prior to planting (20 January to 11 May) and 165 mm in–season (13 May to 11 September). The rainfall received during in–season was 130 mm. Total irrigation plus rain for 2000 was 470 mm. Plots were harvested on 30 October.

Soil matric potential was estimated each week during the growing season using Watermark (Irrometer, Riverside, Calif.) granular matrix devices buried at 0.3, 0.6, and 0.9 m depths below the surface. Because of limited resources, these devices were not replicated and as a result the data is not shown; however, they did provide the cooperating producer some qualitative insight of soil water status.

Yield and quality data were taken from the center eight rows of each plot using a John Deere 7455 cotton stripper (John Deere and Co., Moline, Ill.). Seed cotton was weighed for each replication, and a portion (600 gr) was ginned at the Texas A&M Agricultural Research and Extension Center in Lubbock, Texas. Lint was analyzed for fiber quality with the High Volume Instrument (HVI) system at the International Textile Center of Lubbock. The HVI measured micronaire, length, strength, and uniformity.

The loan base rate was determined for each individual sample from the HVI lint quality parameters. The process of determining Commodity Credit Corporation (CCC) values was a stepwise process, in which loan base values were determined first based on color, leaf grades, and staple length. Discounts were then added or subtracted to the loan base value depending on the micronaire, strength, uniformity and staple length. The sum of the base loan values and these discounts equal the CCC loan value. The quality factors considered for the calculation of the CCC value varies depending on the location within the cottonbelt and from year to year.

The yield and quality data were analyzed with a general linear model (GLM) with mean separation by the Duncan's multiple range test (SAS, 1991), where differences were considered significant at $\alpha < 0.01$.

RESULTS

The effect of irrigation frequency on yield, cotton quality, and gross return was evaluated separately. Quality determines the final price of the crop. Lint yield and quality measures are summarized in tables 2 and 3 for 1999 and 2000, respectively.

COTTON LINT YIELD

In both years, there were no significant differences between frequency treatments for seed weight, percent lint, or lint yield; however, each factor was slightly numerically larger for the high frequency treatments. For 1999, the average seed weight was 2430 kg ha^{-1} for the 4–day irrigation frequency and 2425 kg ha^{-1} for the 16–day irrigation frequency. The percent lint was 27.4% for the high frequency (4–day) and 25.4% for the low frequency (16–day). The cotton lint yield was determined by multiplying the total seed weight by the percent lint. Lint yields for the 4–day frequency were 666 kg ha^{-1} and 616 kg ha^{-1} for the 16–day frequency, a difference of 7.5% (table 2). For 2000, the average seed weight was 2020 kg ha^{-1} for the 2–day irrigation frequency, and 1995 kg ha^{-1} for the 8–day irrigation frequency. The percent lint was 24.0% for the high frequency (2–day) and 23.7% for the low frequency (8–day), and lint yields were 485 kg ha^{-1} (2–day) and 473 kg ha^{-1} (8–day), a difference of just 2.5% (table 3).

COTTON QUALITY

In both years, there were no significant differences between frequency treatments for micronaire, length, strength, and uniformity; however, each factor was equal or numerically greater for the low frequency treatments. An exception was fiber strength in 2000, where the 2–day frequency was slightly greater than the 8–day frequency. For 1999 (table 2), the micronaire, length, strength, and uniformity were 4.4, 25.5 mm, 24.7 g Tex^{-1}, and 79.4%, respectively, for the high frequency (4–day) plots. For the low frequency (16–day) plots, the respective numbers were 4.4, 26.1 mm, 26.2 g Tex^{-1}, and 80.2%. The cotton quality measurements for 2000 were similar to 1999 (table 3). The micronaire, length, strength, and uniformity were 4.1, 25.9 mm, 27.6 g Tex^{-1}, and 79.6%, respectively, for the high frequency (2–day) plots. For the low frequency (8–day) plots, the respective numbers were 4.3, 26.0 mm, 26.8 g Tex^{-1}, and 81.0%.

RETURNS

The 1999 government loan values were based on length, strength, and uniformity. The low frequency (16–day) treatment was $1.13 per kg, significantly greater than the high frequency (4–day) treatment at $1.07 per kg (table 2). The significant difference occurred despite the lack of significance between quality characteristics for 1999. The 2000 government loan values were calculated from uniformity only. The low frequency (8–day) treatment was $1.05 per kg, not significantly greater than the high frequency (2–day) treatment at $1.04 per kg (table 3). In both years, there were no significant differences for gross returns ($ per ha); however, high frequency treatments ($710.15 and $504.50 ha^{-1} for 1999 and 2000, respectively) were numerically greater than low frequency treatments ($694.09 and $497.09 ha^{-1} for 1999 and 2000, respectively).

able 2. Mean values of lint yield, quality, Commodity Credit Corporation (CCC) government loan value[a], and gross return in 1999.

Irrigation Frequency (days)	Seed Weight (kg ha^{-1})	Lint Yield (kg ha^{-1})	Micronaire	Length (mm)	Strength (g Tex^{-1})	Uniformity (%)	Loan Value ($ kg^{-1})	Gross Return ($ ha^{-1})
4	2430	666	4.4	25.5	24.7	79.4	1.07	710.15
16	2425	616	4.4	26.1	26.2	80.2	1.13	694.09
Pr > F	0.9	0.3	0.8	0.02	0.09	0.10	<0.0001	0.7
C.V. (%)	5.1	8.0	3.6	0.67	3.2	.64	0.26	8.2

[a] Loan values were calculated by the Commodity Credit Corporation as if cotton was stored in Sweetwater, Texas considering length, strength, and uniformity.

Table 3. Mean values of lint yield, quality, Commodity Credit Corporation (CCC) government loan value[a], and gross return in 2000.

Irrigation Frequency (days)	Seed Weight (kg ha^{-1})	Lint Yield (kg ha^{-1})	Micronaire	Length (mm)	Strength (g Tex^{-1})	Uniformity (%)	Loan Value ($ kg^{-1})	Gross Return ($ ha^{-1})
2	2020	485	4.1	25.9	27.6	79.6	1.04	504.50
8	1995	473	4.3	26.0	26.8	81.0	1.05	497.09
Pr > F	0.3	0.7	0.1	0.9	0.4	0.14	0.6	0.8
C.V. (%)	2.9	7.3	2.5	1.8	3.9	1.3	2.7	7.6

[a] Loan values were calculated by the Commodity Credit Corporation as if cotton was stored in Sweetwater, Texas considering only uniformity in 2000.

Cotton yield, quality, and gross return were not significantly different for the irrigation frequency treatments evaluated in this study. This lack of response may have been related to the soil water holding capacity of the Reagan silty clay loam providing a buffer effect, resulting in plants from both treatments experiencing the same magnitude and timing of water stress throughout the season, or at least postponing water stress until its influence on final yield and quality was sufficiently diminished. These results agree with prior studies where different irrigation amounts or methods were investigated which generally attributed a lack of yield response to deep soils with sufficient water storage capacity and well–developed root systems (e.g., Hutmacher et al., 1995, 1998). DeTar et al. (1994) reported a yield difference between SDI and furrow irrigation for a non–uniform sandy soil but not for a uniform silt soil. We therefore postulate that irrigation frequency may significantly influence cotton yield or quality if this experiment was repeated on a coarser soil with a much lower or variable water holding capacity.

Summary and Conclusions

The response of cotton yield, quality (micronaire, length, strength, and uniformity), and gross return to two irrigation frequencies under deficit SDI was investigated. The studies were conducted over two years (1999 and 2000) at a commercial farm in St. Lawrence, Texas. Treatments consisted of 4–day and 16–day intervals in 1999 and 2–day and 8–day intervals in 2000. Each treatment was replicated four times, and the same amount of water was applied to each treatment. The soil was a Reagan silty clay loam with a caliche layer just below 0.9 m from the surface.

There were no significant differences in yield, quality measures, or gross return observed between treatments in either year; however, in both years the lint yield and gross return were numerically greater for the low frequency treatments and quality measures were numerically greater for the high frequency treatments. The lint quality characteristics of color, and leaf grade were the same for both frequencies and they were not included in tables 2 and 3. Commodity Credit Corporation (CCC) values computed from length, strength, and uniformity in 1999 and uniformity only in 2000 were significantly greater for the low frequency treatment in 1999 only.

Irrigation intervals of 16 days or less do not appear to influence cotton response using SDI even under deficit conditions, provided soil water holding capacity is adequate (e.g., medium to fine textured soils). We postulate, however, that interval length could become a factor if this experiment was repeated for coarser soils with low water holding capacity, or for shallow rooted crops. This result may have an impact on the agronomic practices of the region where water is very limited but soils are medium to fine textured, as low frequency irrigation allows farmers more flexibility with farm operations, as well as avoiding the additional expense of automating their microirrigation systems.

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